U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-271 905

An Assessment of the Machinery Noise Problem of the Fabricated Metal Products Industry

IIT Research Inst, Chicago, Ill

Prepared for

Industrial Environmental Research Lab, Cincinnati, Ohio

Jan 76

PB 271 905

January 1975

AN ASSESSMENT OF THE MACHINERY NOISE PROBLEM OF THE FABRICATED METAL PRODUCTS INDUSTRY

Summary Report J6131

by

E. P. Bergmann
E. B. Ahlers

Contract 68-01-2234

Project Officer

E. Berkau

U.S. Environmental Protection Agency
Industrial Environmental Research Lab
Cincinnati, Ohio 45268

Prepared for

Environmental Protection Agency
5555 River Avenue
Cincinnati, Ohio 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.
3. RECIPIENT'S ACCESSION NO.	PB-277 705
4. TITLE AND SUBTITLE: An Assessment of the Machinery Noise Problem of the Fabricated Metal Products Industry	5. REPORT DATE: January 1978
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): E.F. Borgmann, F.B. Ahlers	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: IIT Research Institute, 10 West 35th Street, Chicago, Illinois 60616	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.: EPA 68-01-2234
12. SPONSORING AGENCY NAME AND ADDRESS: Dr. Paul Pavlis, U.S. Environmental Protection Agency, Office of Noise Abatement and Control (AW-471), 401 M Street, S.W., Washington, D.C. 20460	13. TYPE OF REPORT AND PERIOD COVERED: Interim
	14. SPONSORING AGENCY CODE: 22/82
15. SUPPLEMENTARY NOTES (Continued from box 12)	

16. ABSTRACT

This is a summary report of a pilot study on one noise intensive industry--Fabricated Metal Products (SIC 34). The primary objective of this study was to ascertain if enough information exists in open literature and in private and public sources to allow an assessment of: the machinery noise problem of an industry; the technology available to reduce the machine noise levels; the technology that needs to be developed; the potential ability of the industry to pay for the noise reduction technology development; and the most cost/effective/beneficial means of providing federal research, development and demonstration participation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT: Release Unlimited	19. SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES: 58
	20. SECURITY CLASS (This page): Unclassified	22. PRICE: PC A04/MF A01

EPA Form 2220-1 (9-73)

ABSTRACT

This is a summary report of a pilot study on one noise intensive industry - Fabricated Metal Products (SIC 34). The primary objective of this study was to ascertain if enough information exists in open literature and in private and public sources to allow an assessment of: the machinery noise problem of an industry; the technology available to reduce the machine noise levels; the technology that needs to be developed; the potential ability of the industry to pay for the noise reduction technology development; and the most cost/effective/beneficial means of providing federal research, development and demonstration participation.

Based on this study it is apparent that sufficient information can be gathered from the open literature, OSHA files, Bureau of Labor Statistics Reports and Department of Commerce Reports to evaluate the machinery noise problem of each industry. It was fortunate that the machine groupings and numbers of machines were available from one data source. Also, previous noise measurement studies had been made which allowed the noise level characterization of many of the machine types in the industry. It can be expected that these types of data are not readily available for each of the noise intensive industries. Trade associations had been contacted for information on noise reduction activities. While that data was not strongly in evidence the associations may be sources for data on machine types and numbers. Selected surveys may be required to characterize many of the machines in the various industries. Data on numbers of operators, noise reduction treatments (what there is of them) and economic data on the industries, however, are readily available.

This report is submitted in partial fulfillment of Project Number J6131, Contract Number 68-01-2134, by IIT Research Institute, under sponsorship of the Environmental Protection Agency. Work on this task was completed as of January 1976.

CONTENTS

		Page
Abstract		ii
List of Tables		v
Acknowledgments		vi
Section		
I	Introduction	1
II	Summary	3
	Overall	3
	Machinery Noise and Exposed Machine Operators	4
	Existing and Potential Noise Reduction Technology	6
	A Cost, Cost/Effectiveness Comparison Between the Use of Enclosures vs. Quiet Machines as Noise Reduction Options	11
	An Estimate of the R&D Costs to Develop the Noise Reduction Technology for the Design and Fabrication of Quiet Machines Typically Used by the Fabricated Metal Products Industry	13
	An Assessment of the Machine Tool Builders and the Fabricated Metal Products Industry's Ability to Pay for the Development of Noise Reduction Technology	16
III	Conclusions	20
	Machinery Noise and Exposed Machine Operators	20
	Existing and Potential Noise Reduction Technology	20
	A Cost, Cost/Effectiveness Comparison Between the Use of Enclosures vs. Quiet Machines as Noise Reduction Options	21
	1. Enclosures vs. Incremental Costs of Buying Quiet Machines	21
	2. Enclosures	22
	3. Quiet Machines	23
	4. Productivity Loss	23
	An Estimate of the R&D Costs to Develop the Noise Reduction Technology for the Design and Fabrication of Quiet Machines Typically Used by the Fabricated Metal Products Industry	24
	An Assessment of the Machine Tool Builders and the Fabricated Metal Products Industry's Ability to Pay for the Development of Noise Reduction Technology	24
IV	Recommendations	26
V	References	29

LIST OF TABLES

Table		Page
1	Ranking of Machine Tools and Equipment by Selected Noise Exposure Criteria	7
2	Machine and Enclosure Cost Comparison for the Machine Class	13
3	Quiet Machinery and Enclosure Cost,, Cost/Effectiveness Comparison Summary	14
4	R&D Cost Summary	15

ACKNOWLEDGMENTS

IIT Research Institute staff members working on this study were E. B. Ahlers, E. P. Bergmann, I. B. Fieldhouse and C. Sessions.

Much appreciated technical guidance and assistance were provided by Dr. E. Berhau and S. Cordle of the Environmental Protection Agency.

Technical support was provided by Lyle F. Verges, Consulting Engineer, for the incremental machine costs and productivity losses.

SECTION 1

INTRODUCTION

This is a summary report of a pilot study on one noise intensive industry - Fabricated Metal Products (SIC 34). The primary objective of this study was to ascertain if enough information exists in open literature and in private and public sources to allow an assessment of: the machinery noise problem of an industry; the technology available to reduce the machine noise levels; the technology that needs to be developed; the potential ability of the industry to pay for the noise reduction technology development; and the most cost/effective/beneficial means of providing federal research, development and demonstration participation.

This study was developed on the basis of two previous studies (Reference 1 and 2) which indicated:

- The open literature has the potential of providing data for assessing the technology that has been applied to reduce machinery noise.
- Machinery noise reduction research is receiving relatively little direct federal support.
- There exists a need to identify and scope the machinery noise problem and investigate alternative roles of the federal government in industrial noise related R, D and D.

The Fabricated Metal Products industry was selected for this pilot study because:

- The machinery used in this industry cover a broad range of machine types and therefore any recommendations made for this industry should have application.

- There exists a data base of literature and noise measurement which should be directly applicable to the conduct of this study.

- This industry has been identified as noise intensive, therefore, the findings of this program could have a direct beneficial effect in establishing noise reduction efforts.

The pilot study was structured into closely defined, but related tasks. Task reports were written which could be considered as documents capable of standing on their own or combined into an assessment of the industry. This study, then, produced the following task reports which appears as References 3 and 7:

- Machinery noise and exposed machine operators in the Fabricated Metal Products Industry.

- Existing and potential noise reduction technology for the Fabricated Metal Products Industry.

- A cost, cost/effectiveness comparison between the use of enclosures vs. quiet machines as noise reduction options for the Fabricated Metal Products Industry.

- An estimate of the R&D costs to develop the noise reduction technology for the design and fabrication of quiet machines typically used by the Fabricated Metal Products Industry.

- An assessment of the machine tool builders and the Fabricated Metal Products Industry's ability to pay for the development of noise reduction technology.

This report summarizes the findings, conclusions and recommendations of the task reports of the pilot study. It is suggested that particular task reports be consulted for detailed information.

SECTION II

SUMMARY

OVERALL

Based on this study it is apparent that sufficient information can be gathered from the open literature, OSHA files, Bureau of Labor Statistics Reports and Department of Commerce Reports to evaluate the machinery noise problem of each industry. It was fortunate that the machine groupings and numbers of machines were available from one data source (Reference 8). Also, previous noise measurement studies had been made which allowed the noise level characterization of many of the machine types in the industry (See Reference 2). It can be expected that these types of data are not readily available for each of the noise intensive industries. Trade associations had been contacted for information on noise reduction activities (Reference 2). While that data was not strongly in evidence the associations may be sources for data on machine types and numbers. Selected surveys may be required to characterize many of the machines in the various industries. Data on numbers of operators, noise reduction treatments (what there is of them) and economic data on the industries, however, are readily available.

It was recognized, at the start of this study, that the assessment of noise technology, costs and the ability of the industry to pay for the development of the technology have been treated in various ways and with somewhat controversial levels of success and agreement. It is not suggested that the methodology which was used in this study is "absolute" or "correct". The intent in each task was to use basic information to

the maximum extent, to make assumptions only where required to fill in the data gaps, and to present the raw data and the methodology as openly as possible. This allows the reader to evaluate the basis, the applicability and the differences as they pertain to his problem. Appendicies were added to the task reports which compile much of the original data. These were included to reduce the amount of re-compilation in any additional assessment of this industry.

MACHINERY NOISE AND EXPOSED MACHINE OPERATORS

The objectives of this effort were to:

- Identify all machinery sources of noise in the fabricated Metal Products Industry. The task report of 15 November 1974, Severe Sources of Industrial Machinery Noise, (Reference 2) serves as the basis for the identification of machines. Additional machines were to be added as found.
- Determine typical machine noise levels.
- Group machines by common functions.
- Prioritize machines within groups.

The accomplishments of this study include:

- Data on machine types and numbers of machines were obtained from the American Machinist Inventory of Metalworking Equipment.
- Noise levels of machines were obtained from OSHA files, NOISH files and from articles and papers in the open literature. Noise levels were distributed over the machine types and industries.
- Data on the numbers of machine operators of each class of machine were obtained from Bureau of Labor Statistics reports. These data were distributed over the machine types. Machine types, number of workers exposed, and machine functions served as bases for grouping, ranking and prioritizing the machines within the industry.

The number of machine operators in the Fabricated Metal Products Industry exposed to various noise levels at the operator position, together with

the number of machines involved for 1973 is estimated to be:

		Exposed Operators		
Noise Level (dBA)	Number of Machines	Number	As Percent of 838,080 Total Production Workers	As Percent of 441,974 Total Machine Operators
85 and under	1,986	1,301	[illegible]	0.3
86 to 90	108,968	54,831	7	12
91 to 95	211,792	118,331	14	27
96 and over	403,324	268,622	32	61

		Cumulative Exposed Operators		
Noise Level (dBA)	Number of Machines	Number	As Percent of 838,080 Total Production Workers	As Percent of 441,974 Total Machine Operators
96 and above	403,324	268,622	32	61
91 and above	615,116	387,143	46	87
86 and above	734,084	441,974	53	100

Machine tools are ranked in noise groups:

Machine Class/Type			Noise Level Rank (dBA)
Metal Cutting Machines		Metal Forming Machines	
• Saws	• Lathes	• Riveting Machines	
• Abrasive Wheels		• Forging Hammers	
• Milling Machines		• Presses and Brakes	96
• Shaping Machines		• Headers	and
• Planing Machines		• Rolls and Swagers	above
Joining Equipment			
• Metalizing Equipment		• Manual Arc Welding Group	

Metal Cutting Machines	Metal Forming Machines	
• Drilling, Boring and Tapping Machines	• Wire and Ribbon Formers	91
• Screw Machines	• Bending Rolls	89
• Polishing and Buffing Machines	Joining Equipment	94
• Special Way and Transfer Machines	• Flame Cutting Machines	
• Turret Lathes	• Electric Resistance Welding	

Metal Cutting Machines	Metal Forming Machines	
• Production Type Grinders	• Thread Rolling Machines	90 and below
• Chuckers & Lathes	Other Equipment	
• Threading Machines	• Diecasting Machines	
• Gear Cutting Machines		

Machines were ranked according to three ranking systems to prioritize them for consideration as industrial noise problems in the Fabricated Metal Products Industry. (1) The product of the number of exposed operators (N_p) and the incremental noise emitted above 85 dBA, i.e., N_p·(dBA-85). This mode of prioritizing appears to have most merit since the degree of hearing loss is generally regarded to vary linearly with noise level. (2) The product of the number of exposed workers and noise intensity factor (F_n) which doubles with each 3 dBA increment in noise level. In this case 86 dBA was given an intensity index value of 1.00. This system recognizes intensity as a causal factor in noise induced hearing loss. (3) The product of the number of exposed operators and machine noise level, i.e., N_p·dBA. Results of these rankings are presented in Table 1.

EXISTING AND POTENTIAL NOISE REDUCTION TECHNOLOGY

The objectives of this effort were to:

- Gather pertinent federal and private data on noise reduction treatments and distribute it through the machines of the Fabricated Metal Products Industry.
- Identify existing technology. Noise reduction practices which have been applied to particular machines are identified.

Table 1. RANKING OF MACHINE TOOLS AND EQUIPMENT BY SELECTED WAGE EXPENDITURE CRITERIA

Type of Machine Tool or Equipment	Rankings					
	[illegible] (1954-55)		[illegible]		[illegible]	
	Rank	Index Value	Rank	Index Value	Rank	Index Value
Mechanical Presses (except Forging)	1	1,438.4	2	2,872.7	1	10,178.4
Electric Arcwelding Equipment	2	836.6	5	1,358.7	2	6,980.4
Bending & Forming Machines (Power)	3	488.3	4	1,636.7	6	2,678.3
Punching & Shearing Machines (Power)	4	471.2	3	1,884.1	7	2,472.8
Drilling Machines	5	402.5	8	938.8	5	3,928.1
Grinding Machines	6	398.8	9	733.8	4	3,929.5
Turning Machines	7	358.6	10	695.5	3	4,726.8
Cutoff, Sawing & Filing Machines	8	354.3	6	887.8	9	1,798.4
Riveting Machines	9	282.8	1	11,374.4	11	1,867.7
Electric Resistance Welding Equipment	10	203.9	13	343.9	8	2,129.6
Milling Machines	11	176.8	11	361.2	10	1,535.7
Forging Machines	12	148.5	7	838.4	12	-1,862.2
Polishing & Buffing Machines	13	93.1	15	74.5	13	344.7
Hydraulic & Pneumatic Presses (Except Forging)	14	57.5	14	335.8	15	363.8
Tapping Machines	15	33.3	18	23.5	16	347.6
Wire & Metal Ribbon Formers	16	33.2	17	48.4	18	258.5
Shaping Machines	17	28.6	16	42.7	19	202.1
Flame Cutting Machines	18	26.2	19	15.8	17	344.6
Boring Machines	19	17.6	21	12.4	21	186.1
Other Metal Forming Machines (Roll Forming, etc.)	20	10.8	22	9.8	14	395.6

described, and where possible, quantified as to the level of noise reduction achieved or possible. Areas of potential transfer of demonstrated technology are identified for other machines with similar functions.

- Identify potential technology. Federal programs and other appropriate sources are reviewed with the intent of identifying areas in which advanced technology can be transferred to achieve industrial machinery noise reduction. This was accomplished by identifying common functions and the noise reduction achieved or possible.

- Identify area in which technology is needed. It became apparent that there are machine groups for which no noise reduction measures have been applied and no existing or potential technology appears to be directly applicable. These "holes" are identified as areas in which technology is needed. Where possible, these areas are identified relative to machine functions to narrow the scope and increase the potential application.

The tasks relating to these objectives were completed and are reported in Reference 4. Accomplishments of this effort include:

- 151 articles, papers, abstracts, and OSHA noise file cards were reviewed, processed into data sheets and distributed over 19 industries.

- Noise treatments were identified and segregated by machine class, machine type, subassemblies and components.

- Federal programs were reviewed, areas of noise reduction research with potential application to industrial machinery noise were identified and the potential applications were distributed over the major subassemblies.

- Areas of needed technology were identified from both machinery and subassembly applications.

The findings of this study are summarized:

- Noise Technology Data. Although the primary thrust of the data gathering activity was directed toward the Fabricated Metal Products Industry the data collected was found to be germain to 13 industries. A review of these data indicated:
  - information on noise level before treatment was given in 34 percent of the cases,

- Noise levels after treatment were given 58 percent of the time,
- Cost data was available on 35 percent of the cases,
- The treatment used was described nearly every time (98 percent), and
- Relatively little information was available on materials, design practices, analysis, deleterious effects and measurement techniques.

- Identification and Distribution of Existing Technology. The most common noise reduction treatment, and the most effective is the use of an enclosure. The effectiveness of enclosures varied from a high of 24 dBA to a low of 9 dBA noise reduction. Costs varied from $25,000 to $450 per enclosure. Process substitution is also a viable noise reduction treatment in particular cases. Component treatments are usually combined to achieve meaningful levels of noise reduction.

- Potential of Transferring Technology from Federally Funded Programs. Federally funded aircraft, surface transportation and machinery noise reduction programs were reviewed for applicability to the industrial machinery noise problem. Based on this review it is evident that a significant technology transfer potential exists. Both development and basic research federal programs are identified.

- Technology Needed. Needed technology includes: A systematic investigation of the functions of each machine in terms of noise and efficiency to establish quiet and efficient means of performing the overall functions; quantitized cause and effect relationships for mechanical, electrical, hydraulic and pneumatic systems; a fundamental understanding of the cutting and forming process noise generation and reduction; and a fundamental understanding of absorption and damping materials in terms of material properties with respect to sound pressure, energy and frequencies.

As an overall summary, it is apparent that a good deal of information on noise reduction treatments exists in the open literature. However, except for a few isolated instances the treatments are not documented well enough to allow either duplication or meaningful extensions of the previous work. Most treatment discussions are in the form of generalities and are results-oriented. These types of discussions can be expected in industrial

applications where the investigator's primary job is to get a quiet machine at the lowest cost. The result, however, is that a scientific, quantitized cause and effect technology base is virtually nonexistant and must be established if efficient noise reduction treatments are to be effected.

A COST, COST/EFFECTIVENESS COMPARISON BETWEEN THE USE OF ENCLOSURES VS. QUIET MACHINES AS NOISE REDUCTION OPTIONS

The objectives of this effort were to:

- Estimate costs of implementing existing and potential noise reduction technologies. The machines, the applicable noise reduction techniques and the required levels of noise reduction were to be examined and an estimate made as to the approximate cost to reduce the machine noise levels.
- Conduct a cost, cost/effectiveness analysis that considered:
  - Cost to reduce noise levels to various levels.
  - A productivity.
  - A capital investment.
  - Number of operators exposed.
  - Number of machines quieted.
  - Mean noise levels of machines in the industry.

The tasks relating to this objective were completed and are summarized in this document. Accomplishments of this study include:

- Enclosure sizes and costs were estimated for 443 machines and distributed over the 160 machine types, 31 machine classes and 5 machine groups of the Fabricated Metal Products industry.
- Incremental machine costs and productivity losses were estimated for 160 machine types and distributed over the 31 machine classes and 5 machine groups of the industry.
- Cost and cost/effectiveness analyses were conducted for the options of using enclosures to reduce machine noise levels or purchasing quiet machines as replacements for noisy machines.

Table 2 is a compilation of average costs and total cost for each machine class. Incremental machine costs and enclosure costs are compiled in adjacent columns. A comparison of the average costs indicates:

- Average incremental machinery costs are consistently below average enclosure costs. The only inverse of this position is for the riveting machines - in this instance the costs of each option are approximately equal.
- The relative high cost - low cost trend is reasonably consistent. A machine class in which the enclosure cost is below the average for the industry generally has a Δ machine cost below the industry average. The exceptions are in the classes of planing machines, bending and forming machines, and cleaning and finishing equipment. In these classes the Δ machine costs are significantly below the enclosure costs.

An inspection of the total cost indicates:

- The average cost trends discussed above also apply to the total costs for the machine classes.
- The total cost for the industry is significantly less (5.3 billion dollars) if the quiet machinery option is selected.

Table 3 is a comparison compilation of costs and cost/effectiveness of quiet machinery vs. enclosures for the five machinery groups. The following are noted:

- The total quiet machinery costs is significantly below that of enclosures.
- Similarly, the average incremental cost per quiet machine is almost half the cost of the average enclosure.
- The incremental cost of quiet machines is uniformly below the enclosure costs.
- On a cost/effectiveness basis the quiet machine is a better choice.

Table 5: MACHINE AND ENCLOSURE COST COMPARISON FOR THE MACHINE CLASS

Machine Class	Average A Machine Cost ($)	Average Enclosure Cost ($)	Total A Machine Cost for Machine Class (Millions of Dollars)	Total Enclosure Cost for Machine Class (Millions of Dollars)
Turning Machines	8,000	3,000	973	1,477
Boring Machines	4,300	4,700	533	557
Drilling Machines	1,400	1,800	565	1,001
Milling Machines	8,000	3,500	836	1,165
Multifunction Machines	4,300	5,000	66	76
Special Way & Transfer Machines	10,000	13,300	149	198
Automatic Assembly, Tapping and Threading Machines	4,000	4,400	377	391
Broaching Machines	3,500	4,600	91	96
Planning Machines	3,000	13,000	38	250
Shaping Machines	3,500	3,500	71	71
Cutoff, Sawing and Filing Machines	1,600	1,000	347	583
Grinding Machines	1,600	2,600	780	1,469
Honing Machines	1,985	3,100	31	49
Lapping Machines	1,500	2,300	30	50
Polishing & Buffing Machines	1,100	1,100	102	102
Gear Cutting & Finishing Machines	3,000	3,100	83	139
Electrical Machining Units	3,000	3,300	32	46
Other Metal Cutting Machines	1,300	1,000	33	47
Bending & Forming Machines - Power	1,500	8,000	152	759
Hydraulic & Pneumatic Presses	3,700	5,900	182	301
Mechanical Presses - Power	3,800	4,600	905	1,109
Punching & Shearing Machines - Power	3,700	3,700	261	377
Forging Machines	8,600	9,300	233	258
Wire & Metal Ribbon Formers	5,000	5,863	130	152
Riveting Machines	3,000	1,900	111	108
Other Metal Forming Machines	3,000	3,900	78	111
Electric Arcweld'ng Equipment	400	1,600	165	590
Electric Resistance Welding Equipment	1,500	3,700	156	370
Other Joining Equipment	1,000	1,600	11	111
Diecasting Machines	0	5,100	0	61
Cleaning and Finishing Equipment	3,500	7,200	365	1,052
		TOTALS	7,000	12,650

Table 3. [illegible]

Machine Group	Total Quiet Machinery Cost for Group (Millions of Dollars)	Total Enclosure Cost for Machine Group (Millions of Dollars)	Average Quiet Machine Cost per Operator ($)	Average Enclosure Cost per Machine ($)	Average Quiet Machine Cost/ Effectiveness Ratio ($/dBA) to 85 dBA	Average Enclosure Cost/ Effectiveness Ratio ($/dBA) to 85 dBA
Metal Cutting Machines	4,467	7,177	1,881	3,038	289	325
Metal Forming Machines	1,934	3,379	2,750	4,805	267	319
Joining Equipment	332	981	667	1,970	44	178
Diecasting Machines	0	61	0	5,437	0	0
Cleaning & Finishing Equipment	365	1,052	2,500	7,205	156	450
TOTALS	7,098	12,650	1,908 (Average)	3,400 (Average)	195 (Average)	306 (Average)

AN ESTIMATE OF THE R&D COSTS TO DEVELOP THE NOISE REDUCTION TECHNOLOGY FOR THE DESIGN AND FABRICATION OF QUIET MACHINES TYPICALLY USED BY THE FABRICATION METAL PRODUCTS INDUSTRY

In order to provide a basis for estimating the R&D costs an approach had to be postulated as to how the R&D would be conducted. Two alternate approaches are presented and compared. The first approach considers the development of quiet components and assemblies. The assemblies are then integrated into quiet machines typical of machines in each of the 31 machine classes within the industry. This approach is characteristic of a federally funded R, D and D program.

The second approach considers the development of machines typical of each of the 160 machine types within the industry. This approach is more characteristic of an industry's approach to the problem. Both approaches are developed from a common phase which structures the problem.

A summary of the R&D costs are given in Table 4.

Table 4. R&D Cost Summary

Phase I - Structure the Problem Cost = 4.75 million dollars	
Phase IIA - Technology Development Demonstration Hardware Cost = 18.73 million dollars	Phase IIB - Technology Development Quiet Machine Types Cost = 117.5 million dollars
Total = 23.5 million dollars	Total = 117.5 million dollars

If Phase II costs are compared - since this phase relates to the development of the technology - it is seen that the technology demonstration program (Phase IIA) costs about 18.7 million dollars to develop 31 demonstration machines. The average R&D cost is $603,000/machine. The quiet machine development option (Phase IIB) costs about 112.8 million dollars to develop 160 quiet machines. The average R&D cost of the option is $70:,000/machine.

AN ASSESSMENT OF THE MACHINE TOOL BUILDERS AND THE FABRICATED METAL PRODUCT INDUSTRY'S ABILITY TO PAY FOR THE DEVELOPMENT OF NOISE REDUCTION TECHNOLOGY

Shop noise in the Fabricated Metal Products Industry (SIC 34) stems largely from operation of machines manufactured in the metalcutting machine tool industry (SIC 3541) and metalforming machine tool industry (SIC 3542). Equipment supplied by manufacturers in still other industries is also involved.

Three approaches to noise control can be applied, either singly or in combination and each can appear most feasible in individual instances.

1. Reduction of noise emanated from the machine tools themselves, through improved new model design and/or retrofit of existing machines.
2. Interruption to the sound path by machine enclosures.
3. Personal protection by ear plugs and other devices.

Noise control expenditures of the following types would be incurred by the involved industries.

- Machine tool manufacturing
  - R&D and redesign costs to develop quieter models
  - Incremental production costs to introduce noise control in new models
- Fabricated Metal Products Industry
  - Retrofit packages or enclosures for current machines
  - Ear protection devices

The ability to incur noise control expenditures is studied separately for the metalworking machine tool industries (SIC 3541 and 3542) and the Fabricated Metal Products Industry (SIC 34). The two groups are decidely different in economic aspects. The metalworking machine tool industry is a highly cyclical industry - much more so than its major customer industries - and its profit ratios and new capital expenditures vary with its cyclical sales pattern. The Fabricated Metal Products Industry includes producers of a broad spectrum of both industrial and consumer products. Its recent history is much less cyclical. It includes a high percentage of small producers.

Factors reviewed in this study of the industry's capacity to pay for pollution control in shops of the Fabricated Metal Products Industry include the following: return on stockholders equity, debt pressure, new capital expenditures, and profits. To the extent possible these factors are related to the size distribution of establishments. Cognisance is thus given to the fact that statistically-derived funds may adequately reflect the capabilities of only the larger establishments.

The following summary statements regarding the metalworking machine tool industries (SIC 3541 and 3542) result from this study.

- The metalworking machine tool industries are highly cyclical, and experienced a 50 percent drop in sales from 1967 to 1972 (in price-deflated dollars).

- Large companies are highly significant in this industry; 10 percent of producers account for about 70 percent of industry sales.

- Among manufacturing industries, metalworking machinery is among the leaders in after-tax profits on stockholders equity in "good" years (17.1 percent in 1966) and among the bottom in "bad" years (3.8 percent in 1972).

- Nine-year (1965 to 1973) average annual after-tax profits on stockholders equity were at the same level for metalworking machinery (11.3 percent), all manufacturing corporations (11.3 percent), and durable goods producers (11.7 percent).

- Average annual profit on stockholders equity for 1965 to 1973 was near the same level as its leading customer industries - fabricated metal products and other machinery producers (11.7 to 12.1 percent), aircraft (10.8 percent), - but lagged motor vehicles (13.4 percent).

- The industry's nine year average profit on stockholders equity equalled or exceeded that of other industries incurring substantial pollution control expenditures - basic chemicals (11.2 percent), paper and allied products (9.2 percent), and primary iron and steel (7.5 percent).

- Indicators of debt pressure were more favurable in the metalworking machinery industry than in among other machinery producers and metalworking corporations, including those of the Fabricated Metal Products Industry.

- Many individuals established are below levels of new capital expenditure where moderate diversion would produce substantial funds for noise control expenditures. About 4 percent of companies, accounting for 30 percent of industry sales, had new capital expenditures estimated at $1,000,000 or more in 1967 -- a "good" business year in the industry. In 1967, 3 percent of establishments accounting for 30 percent of sales, had new capital expenditures estimated at $250,000 or more -- a drop of 75 percent in new capital expenditures per establishment.

- Machine tool exports are a highly significant factor in the metalworking machine industries and appear independent of the domestic cyclical experience in the industry. The industry has experience an increasing secular trend in value of export in recent years.

The following summary statements regarding the Fabricated Metal Products Industry (SIC 34) result from this study.

- The fabricated metal products industry has a pronounced small business component with 73 percent of employees working in units with less than 500 employees and 56 percent in units with less than 250 employees. This compares with 58 percent and 42 percent, respectively, for all manufacturing industries.

- Total value of shipments, in constant dollars, has increased in all years since 1961 except for a 5 percent drop from 1969 to 1970.

- Profits (return on equity) fluctuate widely, the industry ranging from "considerably better" to "considerably worse" than the average for all manufacturing industries.

- Long-term return on stockholders equity (1965 to 1973) has been slightly above that for the more global corporate groups, "all manufacturing corporations" and "durable good producers".

- Indicators of debt pressure are less favorable in Fabricated Metal Products than in metalworking and "other" machinery, but more favorable than in electrical machinery. Indicators of debt pressure have increased steadily during the 1965 to 1973 period.

- Most establishments did not generate funds for large new capital expenditures in the last two business census years. About 3 percent of establishments, accounting for about

40 percent of sales, made new capital investments estimated at $500,000 or more. About 6 percent of establishments, accounting for 50 to 60 percent of sales, made new capital expenditures estimated at $250,000 or more.

- Only about 3 percent of industry establishments, accounting for less than 50 percent of industry shipments, generate before-tax profits of $1,000,000 or more.

SECTION III

CONCLUSIONS

Conclusions relating to the five task reports follow.

MACHINERY NOISE AND EXPOSED MACHINE OPERATORS

It is concluded that:

- Of 838,000 production workers in the Fabricated Metal Products Industry, 442,000 (53 percent) are machine operators exposed to noise levels above 85 dBA, 387,000 (46 percent) above 90 dBA, and 269,000 (32 percent) above 95 dBA.
- The age distribution of machines in the industry indicates that long lead time will occur beyond the date of availability of quiet machines to achieve any substantial reduction in the number of exposed operators solely by normal machine replacements.

EXISTING AND POTENTIAL NOISE REDUCTION TECHNOLOGY

Based on a review of the machinery noise data base relevant to the Fabricated Metal Products Industry these conclusions are offered:

- The open literature contains a significant number of articles on machinery noise reduction treatments.
- OSHA files are potentially a valuable source of data on machinery noise levels, treatments, costs and effectiveness of treatments.
- The most effective and widely used noise reduction treatment for existing machinery is the enclosure.

- Process substitution, whereby a quiet machine is substituted for a noisy one, is a viable alternative for particular applications.

- Reworking or retrofitting existing machines generally requires the application of several subsystem noise reduction treatments to effect a significant (>10 dBA) level of noise reduction.

- There exists a potential for transferring noise reduction technology from federally funded programs to the industrial sector for machinery noise control.

- Papers and articles describe the isolation of noise sources, noise treatments, and the effectiveness of the treatments. Relatively few are well enough documented to allow duplication of the treatment. Virtually none allows a quantifiable extension of the treatment of other machines or subsystems. The technology of noise control needs to be brought out of the realm of an art into that of a science.

A COST, COST/EFFECTIVENESS COMPARISON BETWEEN THE USE OF ENCLOSURES VS. QUIET MACHINES AS NOISE REDUCTION OPTIONS

The conclusions of this study are summarized in four sections.

1. ENCLOSURES VS. INCREMENTAL COSTS OF BUYING QUIET MACHINES

In comparing the incremental cost* of buying quiet machines versus enclosing the machines the average incremental machine costs are consistently below enclosure costs. On an industry wide basis the total cost to the industry is about 5.2 billion dollars less if: 1) all of the machines in the industry with noise levels above 85 dBA are treated; 2) all of the machines are either enclosed or quiet machines are purchased; and 3) the quiet machinery option is selected.

Confounding factors which relate to the quiet machinery option on an individual machine purchase basis include:

---

* The incremental cost is the increase in capital equipment cost associated with implementing noise reduction technology on a particular machine type (e.g. lathe), machine class (e.g. turning machines) or machine group (e.g. metal cutting machines).

- The life cycle status of the machine such that a new machine may not be warranted. In this case the cost of the new machine plus the incremental cost must be considered and evaluated against the option of enclosing the current machine.

- The quiet machine may not be available on the market.

- A quiet process may be substituted for a noisy process to achieve a least cost solution.

The comparison does, however, indicate that there is a significant long term economic payoff in developing quiet machines to reduce the noise exposure levels of the machine operators.

2. ENCLOSURES

The analysis of the use of enclosures as a noise control option indicates:

- Somewhat over 12.2 billion dollars would need to be spent to enclosure every machine in the industry.

- The average enclosure cost per machine is about $3,400.

- The average enclosure cost per machine operator is about $24,400. (There are significantly fewer machine operators than machines.)

- If the machines are treated in accordance with their noise level rank the average noise level of the industry vs. the cost of enclosing the machines are as follows:

Average Noise Level of Industry (dBA)	Expenditure on Enclosures (Billions of Dollars)	Reduction in Exposed Operators (Thousands)
100	3.1	125
95	7.5	325
90	11.2	505
85	12.3	510
80	12.6	511

3. QUIET MACHINES

The analysis of the use of quiet machines as a noise control option indicates:

- About 7.0 billion dollars would need to be spent by industry as a noise related machine cost.
- The average A machine cost for the industry is about $1,900.
- The cost of protecting each machine operator to a level of 85 dBA is approximately $13,900 for industry wide protection.
- If the noisiest machines are treated in accordance with their noise level rank the average noise level of the industry vs. the incremental machinery costs are as follows:

Average Noise Level of Industry (dBA)	Expenditure on Enclosures (Billions of Dollars)	Reduction in Exposed Operators (Thousands)
100	1.3	125
95	3.5	325
90	6.2	505
85	7.0	510
80	7.1	511

4. PRODUCTIVITY LOSS

There is insufficient and conflicting data on productivity loss due to adding enclosures. Losses as high as 20 percent and increases as high as 11 percent have been cited. Productivity losses have been estimated more explicitly, but perhaps not more accurately, for the quiet machines. Those estimates indicate an average productivity loss for the industry in the order of 9 percent. Most of the productivity loss data were gathered shortly after the machines were modified. During this period the manufacturing processes which were used prior to the modification were either not modified or modified only slightly to accommodate the machinery or equipment change. It appears reasonable to expect that many

of the productivity losses cited can be negated by process optimisation. However, it is also reasonable to expect that in the instances in which the process has been optimised prior to effecting a change to a machine a productivity loss can be expected.

AN ESTIMATE OF THE R&D COSTS TO DEVELOP THE NOISE REDUCTION TECHNOLOGY FOR THE DESIGN AND FABRICATION OF QUIET MACHINES TYPICALLY USED BY THE FABRICATED METAL PRODUCTS INDUSTRY

It is estimated that developing the demonstration hardware costs in the order of 23.5 million dollars. Conversely, developing the quiet machines for each machine type costs in the order of 117.5 million dollars. This study concludes that 94 million dollars can be saved through a closely coordinated R, D and D program over a loosely controlled program for developing and implementing quiet machinery technology typical of each machine type.

AN ASSESSMENT OF THE MACHINE TOOL BUILDERS AND THE FABRICATED METAL PRODUCTS INDUSTRY'S ABILITY TO PAY FOR THE DEVELOPMENT OF NOISE REDUCTION TECHNOLOGY

The following conclusions result from this study:

- Noise reduction in the Fabricated Metal Products Industry can be made economically feasible.
- Many individual firms, both among the machine tool builders who produce the equipment and the Fabricated Metal Products manufacturers who use them in production operations would face difficulty, and even hardship, in generating large funds for noise control if required for a period of a few years. This is especially true if retrofit or enclosure are required on machines in use.
- Economic feasibility will probably require:
  - Time periods permitting improvements and their cost incurrence over an extended period of time.
  - Greater reliance on regulatory noise levels on new machinery than on machines in use.

- Federal assistance in development of noise reduction methodology per machine tools.
- Federal assistance, at least in the form of low-interest small business loans for noise reduction expenditures.

The following conclusions regarding the Fabricated Metal Products industry result from this task effort:

- The average level of new capital expenditures is around $900 per year per employee. The average level of after-tax profits is about $1250 per employee. These levels do not favor the ability of the industry to incur expenditures required to provide noise control for machines in use by enclosures, estimated to be of the level of $3400 per machine. The performance of a great many companies is below these levels.
- The large number of small companies indicates that in-house capability in noise control is undoubtedly lacking in most firms.

The following conclusions regarding the metalworking machine tool industries result from this report:

- The great fluctuation of sales and profits in these industries will affect their ability to incur new noise control expenditures.
- Ability to incur such expenditures will also vary substantially with company size. The largest firms should be able to afford the effort without difficulty, more would be able to do so with difficulty, while the smaller firms would face financial problems.
- The smaller machine tool builders are not expected to have an in-house engineering capability in noise control.
- Industry financial enablement would be greatly facilitated by the availability of results of federally supported R&D in noise control methodology and provisions of low-interest small business loans for noise control effort.

SECTION IV

RECOMMENDATIONS

As a result of this study the following recommendations are offered:

- An index consisting of the product of the number of exposed machine operators and the incremental machine noise level above a selected threshold be used as a criterion for prioritizing machine tools for consideration as industrial noise problems. Expressed mathematically

$$\frac{N_p \cdot [dBA_m - 85]}{1000}$$

where:

N_p = number of machine operators

dBA_m = machine noise level measured at operator position

- Studies similar to that reported herein be conducted for all other industries, starting with the most noise intensive industries.

- The OSHA data sheets provide meaningful information on machinery noise reduction treatments. These sheets should be expanded to more clearly define the data and a greater effort should be made to complete the needed information. Company and product identification can be expunged to protect the anonymity of the source.

- It is generally acknowledged that a theoretical noise analysis of a machine or a subassembly is beyond the current state-of-the-art except for relatively simple mechanisms. The approach to an improved understanding of noise control must, therefore, follow an empirical methodology which, in turn, leads to cause and effect relationships which can be quantified, applied and extended. In turn, these relationships can be examined in

order to generate a meaningful theoretical understanding of the noise generation and control mechanism.

- Of the machine types identified as relating to the fabricated metal products industry only about 32 percent had indications of some sort of noise reduction treatment - other than enclosures. It is also evident that these treatments were extended over relatively few of the subassemblies. A broader, more definitive data base is needed. There is a need, therefore, to conduct a complete survey of noise levels (dBA, by machine type and identify and quantitize the noise output (dB and frequency) of the major subassemblies. The results of this survey, coupled with the number of workers exposed to each machine type will form a firm basis for establishing the need and the priorities for noise control research.

- An area of needed noise control technology is a systematic investigation of the function of each production and nonproduction, metal cutting and metal forming machine type. Existing and alternate functions should be investigated in terms of noise, efficiency and alternative methods of performing the job. It is probable that similar functions will be identifiable across a range of machine types and that noise and efficiency treatments will have an equal range of applicability.

- If the technology for quiet machinery for the Fabricated Metal Products Industry is to be developed it is recommended that this be accomplished by the development of demonstration hardware typical of machines within a machine class.

- Federal assistance will probably be required to small business firms in the industries involved. Two forms of such assistance are recommended for Federal considerations.

  - Federal support of R&D to develop noise control methodology found currently lacking. This is justified on the basis that many firms, both machine tool producers and users, are of a size to have small engineering staffs most probably without noise control specialists. Wide dissemination of results of Federally supported R&D would reduce costs of otherwise duplicative effort.

  - Provision of low-interest business loans through the Small Business Administration (SBA) for new expenditures to be incurred to comply with noise regulations, enacting SBA regulatory changes if so required. Size standards for SBA loan eligibility varies from 250 to 1000 employees, depending on the industry at the four digit SIC level. The impact of noise regulation on these

industries may warrant review of size standards and possibly a revised schedule of size standards for noise control loans both for enablement and incentive.

SECTION V

REFERENCES

1. EPA-600/1-76-016, E. P. Bergmann and I.R. Fieldhouse, Abstracts of the 1971-1974 United States and Foreign Open Literature on Noise, January 1976.

2. E. P. Bergmann, Severe Sources of Industrial Machinery Noise, Task Report on EPA Contract 68-01-2234, November 1974.

3. E. G. Ahlers and E. P. Bergmann, Machinery Noise and Exposed Machine Operators in the Fabricated Metal Products Industry, Task Report on EPA Contract 68-01-2234, July 1975.

4. E. P. Bergmann, Existing and Potential Noise Reduction Technology for the Fabricated Metal Products Industry, Task Report on EPA Contract 68-01-2234, July 1975.

5. E. P. Bergmann, A Cost, Cost/Effectiveness Comparison between the Use of Enclosures vs. Quiet Machines as Noise Reduction Options for the Fabricated Metal Products Industry, Task Report on EPA Contract 68-01-2234, January 1976.

6. E. P. Bergmann, An Estimate of the R&D Costs to Develop the Noise Reduction Technology for the Design and Fabrication of Quiet Machines Typically used by the Fabricated Metal Products Industry, Task Report on EPA Contract 68-01-2234, January 1976.

7. E. G. Ahlers, An Assessment of the Machine Tool Builders and the Fabricated Metal Products Industry's Ability to Pay for the Development of Noise Reduction Technology, Task Report on EPA Contract 68-01-2234, January 1976.

8. The 11th American Machinist Inventory of Metalworking Equipment 1973, American Machinist, October 29, 1973.